

A simple method for monitoring uniformity of epitaxial semiconductor structures

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A simple method for visualization of nonuniformity of planar MBE structures is proposed. The method is based on measuring the relief of the photo-EMF. The method can be applied to a wide variety of semiconductor structures and does not require any expensive equipment.

The molecular beam epitaxy (MBE) technique allows one to obtain semiconductor structures with a specified profile of the bandgap along the growth direction with a spatial resolution of atomic range. These potentialities of the MBE technique make it efficient in creation of new materials with controllable physical properties. The most popular structures obtained, at present, using the MBE technique are quantum wells, quantum superlattices, and quantum dots. Ideal structures of the quantum-well and superlattice - type, by definition, should be uniform in the plane of the structure. The objects like ensembles of quantum dots should be uniform within the scale exceeding the mean distance between the dots. Thus, it can be stated that all the above objects should be, ideally, macroscopically uniform in the plane of the structure. In reality, however, one can never obtain a perfectly uniform planar structure. Nonuniformity of the structure is revealed as a dependence of its physical properties (e.g., of spectral position of its optical resonance) over the plane of the structure. In some cases, this dependence appears to be helpful for experimentalists. It allows one, in particular, to find such a spot on the sample where the spectral position of the optical resonance corresponds to the wavelength of the laser used. It should be emphasized that the nonuniformities of this kind can be conveniently used when they have a smooth monotonic character. In many cases, however, the nonuniformities exhibit a complicated spatial dependence which can be hardly employed for practical purposes. These nonuniformities are usually of macroscopic scale ($\sim 100 \mu\text{m}$) and indicate a nonuniformity of the deposition process over the same scale. To detect nonuniformities of this scale, it is desirable to have a simple method that enables to plot a map of the nonuniformities and to study how they depend on the growth regime, the type of the structure, etc. In [1], there has been proposed a method that allowed one to visualize the dependence of the exciton resonance frequency on position on the sample. This method allows one to evaluate, in an express way, spectroscopic nonuniformity of the sample. It requires, however, a tunable laser and

low temperatures. In addition, it is inapplicable to samples with no optical resonances. In this note, we describe a simple method of mapping the relief of the nonuniformity, which is universally applicable to a great variety of semiconductor structures and does not require any expensive equipment. The method is based on detection of dependence of the photo-EMF, generated by a semiconductor sample, on position of the illuminated spot. In what follows, this dependence is referred to as the EMF relief. If the sample is uniform, this dependence is absent, while its appearance indicates a nonuniformity of the sample. The magnitude of the spatially dependent component of the EMF is taken, in this method, for the measure of the nonuniformity. Schematic of the setup for observation of the photo-EMF relief is shown in Fig.1. The laser beam passes through a simple deflecting system comprised of a mirror attached to a loudspeaker membrane, and is focused and directed to the sample placed in a capacitor with a transparent upper plate. Illumination of a small spot on the surface of the sample produces an electric field in the vicinity of the spot (due to the Demer effect) or changes the build-in field. The laser light intensity is modulated at a frequency of 15-18 kHz, and the induced field oscillates with the same frequency. As a result, an ac voltage arises on the plates of the capacitor, with its amplitude proportional to the photo-EMF generated in the illuminated spot. When the sample is nonuniform, the photo-EMF will vary, thus reflecting the nonuniformity of the sample. As seen from Fig.1, the laser beam in our setup is swept in two directions as it is usually being done in TV monitors. The frame sweep is implemented by a slow translation of the sample in the direction shown in Fig.1 by a broad arrow. The voltage of the capacity varying at the frequency of the laser light modulation is detected and stored in a computer. The 2D array thus obtained which represents a relief of the photoresponse amplitude over the surface of the sample, is displayed on the monitor as a relief of brightness. When the sample under study is uniform, the obtained pattern represents a bright area in the form of the sample. Arising dark and bright spots, in this region, indicate a nonuniformity of the structure. We used, in our setup, a commercial laser pointer, with the intensity modulated, at a frequency of 15-18 kHz, by modulating the feeding current. The line sweep frequency was 17 Hz. The frame sweep rate was chosen to provide 200 lines per frame. As samples for testing, we used epitaxial GaAs/AlGaAs structures. Fig.2a shows a relief of the photo-EMF obtained with a pure GaAs substrate which we used as a reference. A considerable number of structures grown in our laboratory showed a nonuniformity comparable in value with that shown in Fig.2a. To illustrate our technique, we present the results of scanning of the samples with anomalously strong nonuniformity. Fig.2(b,c) shows the relief of the photo-EMF of an epitaxially grown optical waveguide (b) and the same for a GaAs/AlGaAs quantum well (c). As seen from these figures the character of nonuniformity of the structures grown on the same MBE machine may essentially differ. Note that the nonuniformities shown in Fig.2(b,c) cannot be observed using a microscope. At present, we cannot make any definite conclusion about correlation (if any) between the nonuniformity of the photo-EMF and spectroscopic nonuniformity of the sample. This is the objective of our future studies. The study was supported by the International Science and Technology Center (project 2679)

- [1] S.V.Poltavtsev, V.G.Davydov, "Optical method for characterization of the quantum well heterostructures" Abstracts of the VI-th All-Russia Conference of Young Scientists on Physics of Semiconductors and Semiconductor Opto- and Nano-Electronics, SpbGPU, 2004

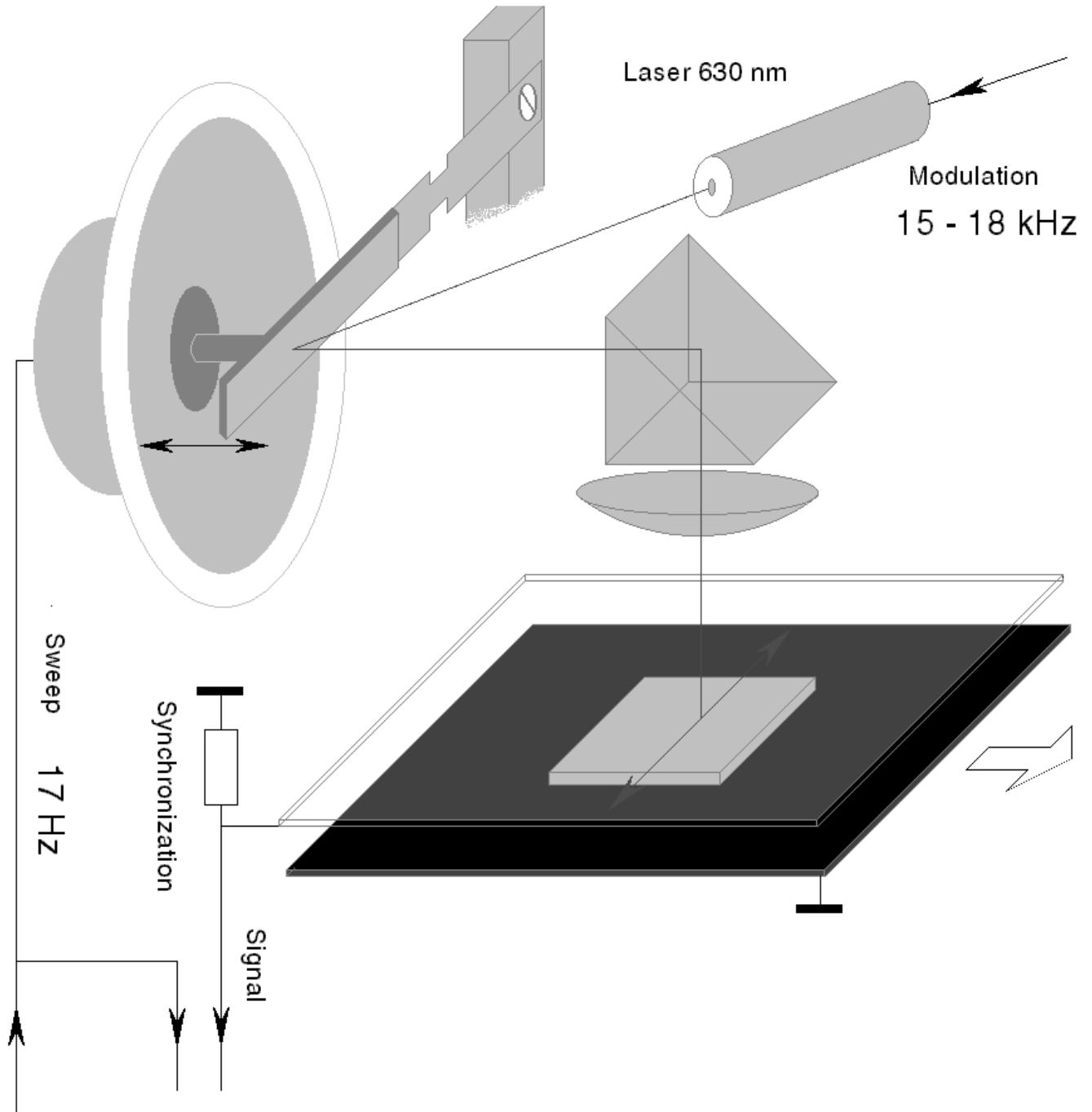


FIG. 1. Schematic of the set-up for observation of the photo-emf relief

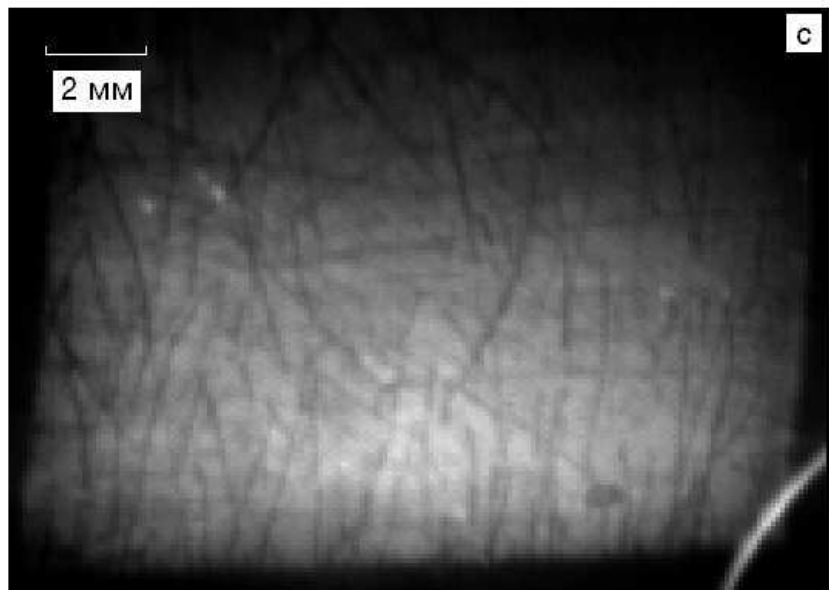
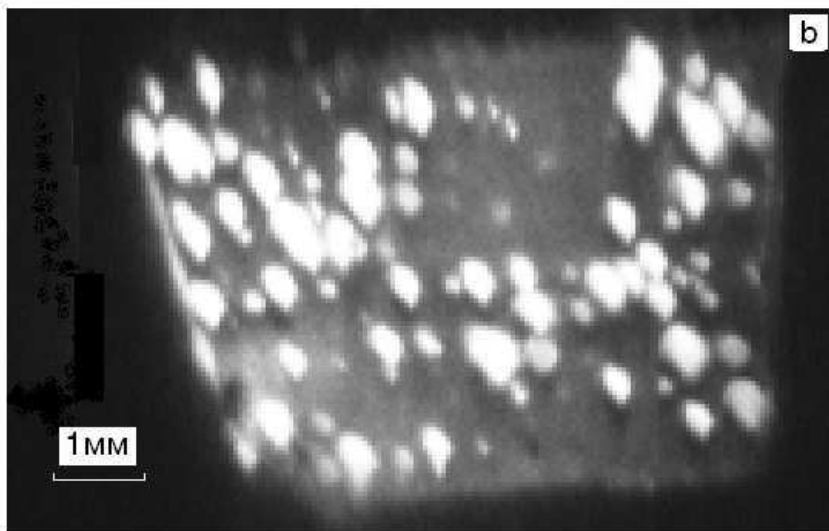
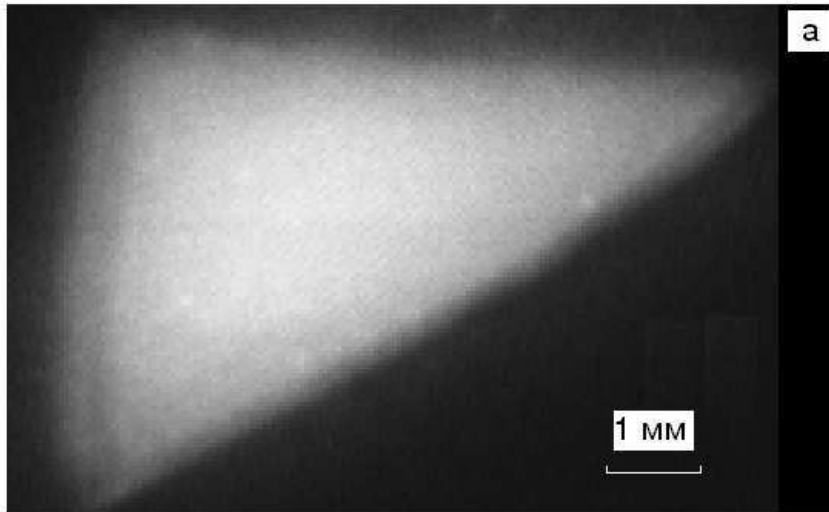


FIG. 2. Examples of the relief of the photo-emf of a pure GaAs substrate (a), a planar waveguide (b), and a quantum well structure (c) grown using the MBE technique.